EFFECTS ON CHAINED-SCHEDULE PERFORMANCE OF RESPONSE-CONTINGENT VARIATIONS IN THE PROBABILITY OF STIMULUS CHANGE

By

RAFAEL BEJARANO

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By

Rafael Bejarano

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Chair: Dr. Timothy D. Hackenberg
Major Department: Department of Psychology

Key pecking of pigeons was studied in 2 experiments to determine whether behavior in chained schedules is sensitive to response-contingent variations in the probability of stimulus change. To this end, the probability of transitions between links in 2-link (Experiment 1) and 4-link (Experiment 2) chains was scheduled to vary as a direct function either of the most recent interresponse time, or of the 4th interresponse time in advance of the most recent one. In both experiments, interresponse times increased in length when the probability of transitions from one link to the next varied with the duration of the most recent interresponse time, but not when the probability of such transitions varied with the duration of the 4th interresponse time preceding the most recent one. Because the procedures used in both experiments kept the duration of each link from varying systematically across conditions, these findings cannot be accounted for in terms of delays to the unconditioned reinforcer signaled by the stimuli correlated with different links in the chains, or

in terms of the contingency between rate of responding in each link and the presentation of the unconditioned reinforcer. Consequently, these results must be attributed to the contingency between responding and stimulus change.

CHAPTER 1
INTRODUCTION

Operant behavior can be defined as behavior that is modifiable by its consequences (Skinner, 1953). Responses that increase in frequency as a result of their consequences are said to be reinforced, and the consequential stimuli are called reinforcers. One question that arises in connection with the study of operant behavior concerns the means whereby extended sequences of responses are generated and maintained. Although the final member of such sequences can reasonably be assumed to derive its strength from the reinforcement that follows it, earlier members are more difficult to explain, due to their temporal distance from reinforcement. The solution to this problem appears to be that early responses in such sequences produce stimulus changes that serve both as reinforcement for those responses and as the occasion for the occurrence of later ones. While making a telephone call, for example, picking up the receiver might produce stimulus changes that function as reinforcement for this act and as the occasion for dialing the number. Likewise, dialing might produce stimulus changes that serve as reinforcement for this act and as the occasion for listening to determine whether the line is busy or not. Finally, listening might be reinforced by the stimuli provided by the voice at the other end of the line.

Evidence for the usefulness of this formulation of the problem comes from studies of behavior maintained by chained schedules of reinforcement. In chained schedules, two or more component schedules are presented in series. The consequence of completing the requirements of one schedule is the initiation of the next schedule, and each component schedule (or link) is correlated with a different exteroceptive stimulus (Ferster & Skinner, 1957; Gollub, 1977; Kelleher, 1966). Chained schedules tend to generate and sustain a great deal of behavior in the links of the chain preceding the terminal link, even though such behavior is not followed immediately by the presentation of an unconditioned reinforcer (e.g., food, water, etc.). Such behavior is often explained in terms of conditioned reinforcement, or the idea that responding in a given link of a chain is maintained by the contingency between its occurrence and the presentation of the stimulus correlated with the subsequent link. In turn, this stimulus is said to acquire its reinforcing efficacy either by being presented in close temporal contiguity to other reinforcers (Kelleher & Gollub, 1962) or by setting the occasion upon which responding produces reinforcement (Keller & Schoenfeld, 1950).

Although conditioned reinforcement continues to be viewed as a likely determinant of behavior in chained schedules, it has proven difficult to dissociate its effects from those of other variables that also might be involved in generating and maintaining such behavior. One such variable is the delay to the unconditioned reinforcer correlated with the different stimuli in a chain (Staddon, 1983). Consider, for example, a two-link chained schedule in which (a) the initial and terminal links are correlated with red and green stimuli, respectively, (b) the onset of green is contingent on the first response occurring 30 s after the onset of red, and (c) food is contingent on the first response occurring 30 s after the onset of green. Under such an arrangement, known technically as a chained fixed-interval (FI) 30-s FI 30-s schedule, the onset of red would signal a 60-s delay to food. Thus, rather than being controlled by the contingent presentation of green, responding in the initial link might be controlled by this relation between the onset of red and the presentation of food.

A second such variable is the contingency between response rates in the early links of a chain and the time to the unconditioned reinforcer. Continuing with the above example, initial-link response rates of less than 2 per min would increase the duration of the initial link, and thereby the time to food. Thus, rather than being controlled by the contingent presentation of green, responding in the presence of red might be controlled by this relation between initial-link response rate and the delay to food.

A number of strategies have been used to dissociate the effects of these variables from those of conditioned reinforcement. Table 1 summarizes a number of the procedures that have been used for this purpose. One approach has been to compare chained and tandem schedules (which differ from one another in that each component in the former schedule is correlated with a different stimulus, whereas all of the components in the latter are correlated with the same stimulus). Transitions from the first to the second link of a two-link chained schedule, for example, might be correlated with a change in the color of the light illuminating the operandum, whereas transitions from the first to the second component of a two-component tandem schedule would not be accompanied by a comparable change in stimulation. Thus, if the contingency between responding and stimulus change (i.e., conditioned reinforcement) is the primary determinant of chained-schedule performance, response rates should be higher in the early components of chained than in the early components of tandem schedules, because only the former schedules arrange such a contingency. However, if the primary function of stimuli in chained schedules is

Table 1. Summary of Combinations of Reinforcement Schedules

	Correlated stimuli	No correlated stimuli
Unconditioned reinforcement after each component	Multiple	Mixed
Unconditioned reinforcement after last	Chain	Tandem

to signal the time remaining until the delivery of the unconditioned reinforcer, then lower response rates would be expected in the early components of a chained schedule than in the corresponding components of a tandem schedule, because only the former schedule arranges stimuli that are differentially correlated with different times to the unconditioned reinforcer. Finally, if the contingency between responding in the early components of a chain and the presentation of the unconditioned reinforcer is the primary determinant of chained-schedule performance, response rates should be approximately equal on the two schedules, because both chained and tandem schedules arrange such a contingency.

Chained-tandem comparisons typically yield higher response rates in the early components of tandem than in the corresponding components of chained schedules. For example, Wallace, Osborne, & Fantino (1982) exposed 12 pigeons to chained and tandem schedules consisting of two FI components. The durations of the initial and terminal components were the same in the chained and tandem schedules, but varied across groups of birds. Four pigeons were exposed to FI 4-s components, four to FI 16-s components, and four to FI 60-s components. Under the two higher FI values (i.e., FI 16-s and FI 60-s), response rates were higher in the initial component of the tandem schedule than in the initial link of the chained schedule. Similarly, chained-tandem comparisons involving three FI components (Kelleher & Fry, 1962; Thomas, 1967), five FI components (Gollub, 1958), three fixed-ratio (FR) components (Jwaideh, 1973; Thomas, 1964), and five FR components (Jwaideh, 1973) all have yielded higher response rates in the early components of the tandem than in the corresponding links of the chained schedules.

Despite its robustness, it is not entirely clear how best to interpret this effect. To be sure, it is consistent with the idea that chained-schedule performance is controlled by the delays to the unconditioned reinforcer signaled by the stimuli correlated with the different links of the chain, rather than by conditioned reinforcement (Staddon, 1983). However, higher response rates in the early components of tandem than in the early links of chained schedules also may reflect discriminative control by the stimulus correlated with the unconditioned reinforcer over responding in the early components of the tandem schedules. In other words, chained-tandem comparisons might yield higher response rates in the early components of the tandem than in the corresponding components of the chained schedules, because the stimulus in the presence of which responding produces the unconditioned reinforcer is correlated with all of the components of the former schedule, but only with the terminal component of the latter. In any case, the contingency between response rates in the early links of chained schedules and the delay to the unconditioned reinforcer is not sufficient to explain chained-schedule performance, as both chained and tandem schedules arrange this contingency, but the above cited chained-tandem comparisons yielded higher response rates under the latter schedules.

Another strategy for investigating whether the contingency between responding and stimulus change determines behavior in chained schedules has been to compare chained and multiple schedules. These schedules resemble one another in that a different exteroceptive stimulus is correlated with each component in both, but unlike chained schedules, the components of multiple schedules alternate response-independently (Table 1). A typical chained-multiple comparison might involve a two-link chained schedule (e.g., chained FI 30-s FI 30-s) and a two-component multiple schedule, the latter consisting of alternating extinction (EXT) and reinforcement components (e.g., Mult EXT 30-s FI 30-s). If the contingency between responding in the initial link of the chain and the presentation of the stimulus correlated with the terminal link is the primary determinant of initial-link responding, then higher response rates would be expected in the initial link of the chained schedule than in the extinction component of the multiple schedule, because only the former schedule arranges such a contingency. However, if initial-link response rates are primarily or entirely determined by the delay-signaling properties of the initial-link stimulus, then response rates in the initial link of the chained schedule should be approximately equal to those in the extinction component of the multiple schedule, given that the stimuli correlated with the initial link in the former and the extinction component in the latter signal the same delays to the unconditioned reinforcer.

Chained-multiple comparisons typically yield higher response rates in the early components of chained schedules than in the extinction components of multiple schedules (Catania, Yohalem, & Silverman, 1980; Ferster & Skinner, 1957, Chapter 12). Although such findings suggest that chained-schedule performance might be determined by the contingency between responding and stimulus change (i.e., by conditioned reinforcement), another possibility is that such performance is determined by the contingency between responding in the early links of a chain and the delay to the unconditioned reinforcer. That is, response rates might be higher in the early components of chained schedules than in the extinction components of multiple schedules, because long pauses in the early components of a chain would delay the transition to the subsequent component, which in turn would delay the presentation of the unconditioned reinforcer.

One way to rule out this possibility is to compare not only chained and multiple schedules, but also tandem and mixed schedules. Tandem and mixed schedules differ from one another in that component transitions are response-contingent in the former but not in the latter schedule, whereas they resemble each other in that the same stimulus is correlated with all of the components in both schedule types (Table 1). Thus, if the contingency between rate of responding and the presentation of the unconditioned reinforcer is responsible for the occurrence of higher response rates in chained than in multiple schedules, then this contingency also might be expected to produce higher response rates in tandem than in mixed schedules, given that tandem (but not mixed) schedules arrange this contingency. However, if the contingency between responding and stimulus change is responsible for the response-rate difference between chained and multiple schedules, then tandem and mixed schedules should yield equivalent rates of responding, given that neither schedule arranges such a contingency.

The aforementioned study by Catania et al. (1980) was designed to tease apart the effects of these contingencies. These investigators compared chained and tandem schedules consisting of three FI 30-s components, and multiple and mixed schedules consisting of two 30-s extinction components followed by an FI 30-s component. They found that higher response rates occurred in the middle link of the chained schedule than in the corresponding component of the multiple schedule, but that response rates in the middle components of the tandem and mixed schedules were not significantly different from one another. In other words, the contingency between responding and the presentation of the unconditioned reinforcer, which was in effect under the tandem but not under the mixed schedule, did not yield different response rates under these two schedules, suggesting that the differences in response rate yielded by chained-multiple comparisons are due to the contingency between responding and stimulus change inherent in chained (but not in multiple) schedules.

A third approach to studying the role of conditioned reinforcement in chained schedules is that taken by Royalty, Williams, and Fantino (1987). Based on the finding that brief unsignaled delays to an unconditioned reinforcer reduce response rates in simple schedules (Williams, 1976), Royalty et al. reasoned that, if the stimulus changes correlated with transitions between the components of a chain have reinforcing effects, then delaying such transitions likewise might be expected to decrease response rates in chained schedules. To investigate this possibility, these researchers arranged a chained variable-interval (VI) 33-s VI 33-s VI 33-s schedule (i.e., a chained schedule in which the duration of each link averaged 33 s, but varied in duration from one presentation to the next). Across experimental conditions, they interposed an unsignaled 3-s delay between either the first and second or the second and third links. To hold constant the time to the unconditioned reinforcer, the schedule in the link wherein the delay was programmed was changed from a VI 33-s schedule to a tandem VI 30-s fixed-time 3-s schedule. That is, the VI schedule was decreased in value by 3 s, and a 3-s delay was appended to it. Royalty et al. found that response rates decreased significantly in the link of the chain in which the unsignaled delay was arranged.

These results are important for two reasons. First, they do not suffer from the interpretive difficulties associated with the results of the chained-tandem or chained-multiple comparisons discussed previously. That is, the findings of Royalty et al. cannot be interpreted in terms of the contingency between responding in the early links of the chain and the delay to the unconditioned reinforcer, or in terms of the delays to the unconditioned reinforcer signaled by the different stimuli in the chain, because these variables were held constant across experimental conditions. Consequently, the contingency between responding and stimulus change (i.e., conditioned reinforcement) is the only variable to which these findings can be attributed. Second, the results of Royalty et al. demonstrate that one of the variables known to affect behavior in simple schedules (reinforcement delay) also affects behavior in chained schedules, suggesting that other variables known to affect responding in simple schedules also might affect chained-schedule performance.

The two experiments reported herein were conducted to investigate this possibility. In particular, two- and four-link chained schedules were arranged in Experiments 1 and 2, respectively, to investigate whether interresponse times (IRTs) in chained schedules are sensitive to response-contingent variations in the probability of stimulus change. A number of studies have demonstrated that IRT duration is a reinforceable property of behavior (Alleman & Platt, 1973; Anger, 1956), and two experiments have shown that varying the probability of food reinforcement as a direct function of IRT duration increases the frequency of long IRTs (Platt, 1979; Weiss, 1970). The latter finding led the present author to speculate that, if the stimuli correlated with the various links of a chain can function as conditioned reinforcers, then varying the probability of component transitions as a direct function of the duration of the IRTs preceding such transitions (and thereby the probability of stimulus change) also should increase the frequency of long IRTs.

This speculation was tested by means of procedures variously known as stochastic reinforcement of waiting (Platt, 1979; Weiss, 1970) and Linear-IRT (Galbicka & Platt, 1984) schedules. To determine the probability of reinforcement under such schedules, the duration of each IRT is divided by the duration of the scheduled mean interreinforcement interval (IRI). Under a programmed mean IRI of 30 s, for example, 6-s and 15-s IRTs would be reinforced with probabilities of 0.2 and 0.5, respectively. Thus, provided that pausing at the beginning of each IRI is not excessive, and IRTs do not exceed the duration of the programmed IRI, obtained mean IRIs will remain relatively constant under such procedures, even though long IRTs might come to predominate.

In the present studies, this characteristic of linear-IRT schedules--that they differentially reinforce long IRTs while holding IRI duration constant--made it possible to reinforce long IRTs differentially in one link of the chain by the transition to the next link, while simultaneously keeping the duration of the interstimulus intervals (i.e., of the components of the chain) relatively constant. In turn, keeping component durations constant provided a means of controlling for the effects of the delays to the unconditioned reinforcer signaled by the various stimuli in the chains, and for the contingency between responding in the early links and the delay to the unconditioned reinforcer.

Two variants of linear-IRT schedules were used to calculate the probability of transitions between links. One variant involved dividing the most recent

(Lag-0) IRT, by the scheduled mean duration of the link in which it occurred, while the other involved dividing the fourth IRT in advance of the most recent one (i.e., the Lag-4 IRT) by the programmed mean duration of the link in which that IRT occurred. The Lag-4 contingencies were arranged, because they were expected to produce effects that might constitute a good point of reference for the effects of the Lag-0 contingencies. In other words, the finding that reinforcement delay diminishes the effectiveness of conditioned reinforcers (Royalty et al., 1987) suggested that the contingency between Lag-4 IRTs and component transitions would not generate long IRTs, since IRTs of any duration might be more temporally contiguous with the onset of the stimulus correlated with the subsequent component than the IRT upon which the probability of component transitions was actually based. However, the contingency between Lag-0 IRTs and component transitions was expected to generate long IRTs, because of the high degree of temporal contiguity between the putative conditioned reinforcer and the IRT upon which its presentation was contingent.

To summarize, although behavior in chained schedules traditionally has been explained in terms of the concept of conditioned reinforcement (Kelleher & Gollub, 1962), the explanatory status of this concept has become less widely accepted, in part because of the recognition that chained-schedule performance also might be accounted for in terms of the delays to the unconditioned reinforcer signaled by the different stimuli in chained schedules (Staddon, 1983), or by the contingency between responding in the early links of a chain and the presentation of the unconditioned reinforcer. Chained-tandem and chained-multiple comparisons, which have been conducted to disentangle the effects of these variables from those of conditioned reinforcement, have not been entirely successful in this endeavor. In contrast, the study by Royalty et al. (1987) found not only that conditioned reinforcement is a powerful controlling variable in chained schedules, but also that the reinforcing efficacy of stimulus change is affected by reinforcement delay, just as the efficacy of food reinforcement is affected, suggesting that other variables known to determine the effectiveness of unconditioned reinforcers likewise might determine the effectiveness of conditioned reinforcers.

To examine whether reinforcement probability might be one such variable, the two experiments reported herein used Linear-IRT schedules to arrange transitions between components in two-link (Experiment 1) and four-link (Experiment 2) chained schedules. Because these schedules differentially reinforce long IRTs while holding constant the duration of each link, any changes in IRT duration that might occur across conditions would not be attributable to the delays to the unconditioned reinforcer signaled by the different stimuli in the chain, or to the contingency between response rate in the early links and the presentation of the unconditioned reinforcer. Consequently, such changes would have to be explained in terms of response-contingent variations in the probability of stimulus change (i.e., conditioned reinforcement).

CHAPTER 2
EXPERIMENT 1

Method

Subjects

Four White Carneau pigeons (*Columba livia*), numbered 68, 790, 2167, and 8269, served as subjects. None had served in other experiments, but all had served in undergraduate laboratory courses on operant conditioning, and thus had been trained to peck response keys. Subjects were maintained at approximately 80% of their free-feeding body weights by means of postsession feedings. Pigeons were individually housed in a colony room, where they had continuous access to water and grit. The room was illuminated on a 16.5:7.5 hr light/dark schedule.

Apparatus

One standard Med-PC (Model #ENV-005) operant conditioning chamber for pigeons (30.1625 cm long, 30.1625 cm wide, and 31.75 cm high) was used. The experimental chamber was enclosed in a sound-attenuating shell. Three response keys (2.54 cm in diameter) were located on the experimental panel 23.2 cm above the grid floor. The left and right keys were 5.8 cm and 5.5 cm from the left and right walls, respectively, whereas the center key was located 5.8 cm from both the left and right keys. A force of approximately 36 grams was required to operate the response keys; only the left response key was used in the experiment.

A houselight, centrally located overhead as part of the sound-attenuating shell, provided diffuse illumination, and a centrally located aperture, measuring 4.5 by 5.2 cm and positioned 6.7 cm above the grid floor, provided access to mixed grain. A ventilation fan and a white noise generator helped mask extraneous sound. An IBM-compatible microcomputer (using Med-PC software) scheduled the presentation of stimuli and recorded the occurrence of key pecks at a sampling rate of 200 times per second. The computer was located in a room some distance from that in which the experimental chamber was located.

Procedure

A two-link chained schedule was used. In the initial link of the chain, a red key light illuminated the left key, and a linear-IRT schedule was used to calculate the probability of transitions to the terminal link. Depending on the experimental condition (see below), this involved dividing either the most recent IRT, or the fourth IRT in advance of the most recent one, by 30 s (the programmed mean duration of the initial link). In the terminal link, a white key light illuminated the left key, and an RI 30-s schedule of food presentation operated (i.e., food presentations were arranged by sampling a probability gate every 0.3 s with a probability of 0.01). Food presentations consisted of 3-s access to a food hopper, during which times the feeder light was illuminated, and the houselight and all key lights were dark. After the 3 s of food access, the food hopper was withdrawn, and the initial-link schedule was reinstated, thereby beginning a new cycle.

Each experimental session consisted of 30 such cycles. Sessions were conducted 7 days per week, except on rare occasions (e.g., in cases of equipment failure). The primary dependent measures collected in each session were mean initial- and terminal-link IRTs, absolute frequency distributions of all initial- and terminal-link IRTs (in .5-s bins), mean durations of the initial and terminal links, and latencies to the first initial- and terminal-link responses of each cycle.

Four experimental conditions were conducted. In Conditions 1 and 3 (designated the Lag-4 conditions), the probability of transitions from the initial to the terminal link was calculated by dividing each Lag-4 IRT in the initial link by 30, the programmed duration (in seconds) of the initial link. In Conditions 2 and 4 (designated the Lag-0 conditions), this probability was calculated by dividing each Lag-0 IRT in the initial link by 30. The terminal-link schedule was the same in all conditions of the experiment, and consisted of the RI 30-s schedule of food presentation described previously. All subjects were exposed to the conditions in the order Lag-4, Lag-0, Lag-4, Lag-0.

In all conditions, the first four IRTs of each session and all latencies to the first initial-link response of each cycle were excluded from calculations of the probability of transitions to the terminal link. The former were excluded because at least four IRTs had to occur before the contingencies could go into effect in the Lag-4 conditions. In other words, the probability with which the terminal link went into effect depended on the fourth IRT in advance of the most recent one when the Lag-4 contingencies were operating, which meant that the first calculation of this probability in each session could not be made until a minimum of four IRTs (or five responses) had occurred. To keep this procedural feature constant throughout the experiment, the first four IRTs of each session were also excluded from calculations of the probability of transitions to the terminal link during the Lag-0 conditions. Similarly, latencies to the first initial-link response of each cycle were excluded because they are not in the same class of temporal events as IRTs. That is, whereas IRTs were measured from the time between one key peck and the next, latencies to the first initial-link response of each cycle were measured from the presentation of the initial-link stimulus.

Each condition remained in effect for a minimum of 15 sessions, and for as many additional sessions as were required for responding to meet the stability criteria. In particular, no upward or downward trend could be apparent in the mean initial-link IRTs from the most recent five sessions. Moreover, the amount of variability over the most recent 10 sessions had to be minimal, as determined in the following manner: First, two grand means were calculated, one based on the mean IRTs from each of the most recent five sessions and another based on the mean IRTs from each of the preceding five. Then, the difference between the grand means was calculated. If this difference was less than .1, responding was deemed stable, and the subject was advanced to the next condition, or in the case of the final condition, the experiment was terminated.

Results

Figures 1 through 4 show mean initial- and terminal-link IRTs (top graphs) and mean initial- and terminal-link durations (bottom graphs) from the final five sessions of each condition for each subject. Taking up the latter measure first, the durations of the initial and terminal links varied unsystematically across conditions. The mean durations of the initial links, calculated from the last five sessions (150 cycles) of each condition, ranged from 30.2 s (Subject 68, Condition 2) to 38.3 s (Subject 2167, Condition 2). The mean durations of the corresponding terminal links ranged from 26.8 s (Subject 68, Condition 1) to 31.4 s (Subject 790, Condition 2).

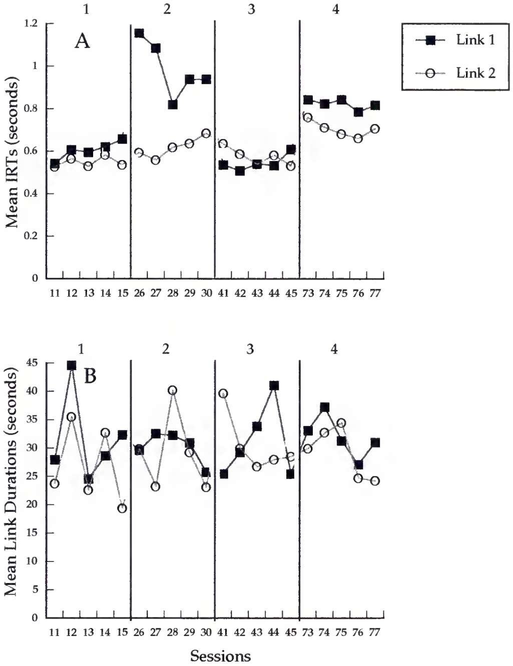

Figure 1. Summary of the results from Experiment 1 for Subject 68. Part A of the figure shows the mean IRTs in Links 1 and 2. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect in Conditions 1 and 3. Lag-0 contingencies were in effect in Conditions 2 and 4.

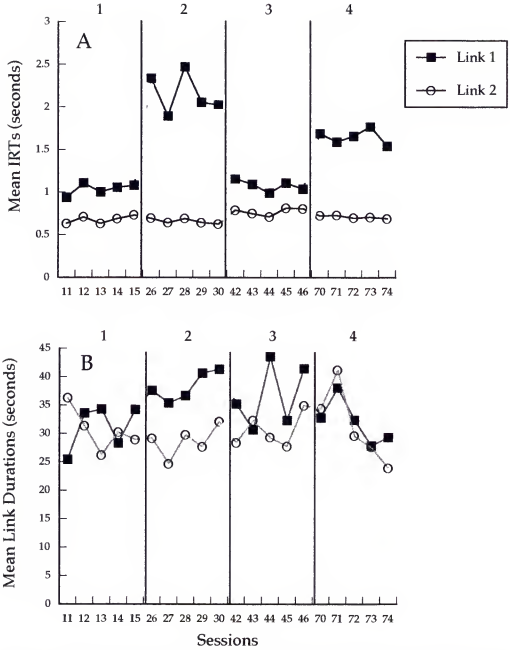

Figure 2. Summary of the results from Experiment 1 for Subject 2167. Part A of the figure shows the mean IRTs in Links 1 and 2. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect in Conditions 1 and 3. Lag-0 contingencies were in effect in Conditions 2 and 4.

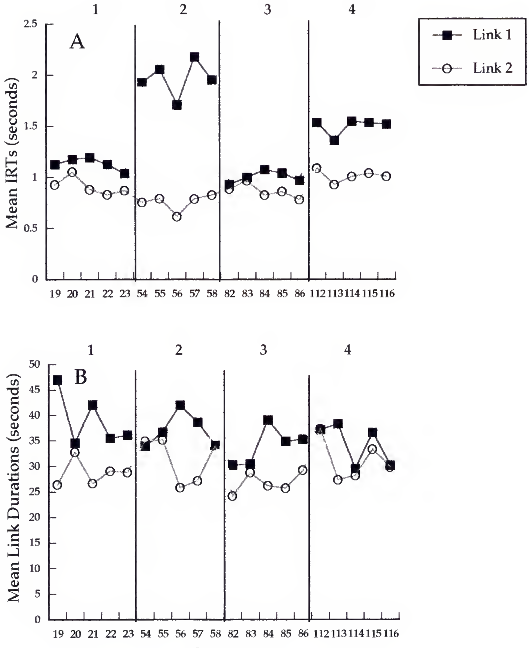

Figure 3. Summary of the results from Experiment 1 for Subject 790. Part A of the figure shows the mean IRTs in Links 1 and 2. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect in Conditions 1 and 3. Lag-0 contingencies were in effect in Conditions 2 and 4.

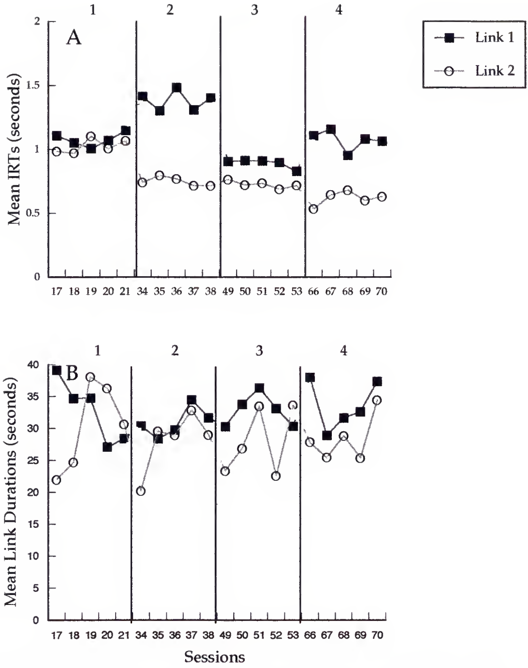

Figure 4. Summary of the results from Experiment 1 for Subject 8269. Part A of the figure shows the mean IRTs in Links 1 and 2. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect in Conditions 1 and 3. Lag-0 contingencies were in effect in Conditions 2 and 4.

Mean terminal-link IRTs also varied unsystematically across conditions, with the possible exception of Subject 8269, for which mean IRTs were shorter in the Lag-0 than in the preceding Lag-4 conditions. This effect probably is not related to the across-condition changes in the contingencies, given that this subject's terminal-link IRTs tended to become shorter throughout the experiment.

Mean initial-link IRTs varied as a function of whether the Lag-0 or the Lag-4 contingencies were in effect. Moreover, larger increases in IRT duration occurred during the first exposure to the Lag-0 contingencies (Condition 2) than during the second exposure (Condition 4). Averaged across subjects, IRTs in the initial link increased in duration by 68% during Condition 2 (range = 28% for Subject 8269 to 107% for Subject 2167); and by 43% during Condition 4 (range = 20% for Subject 8269 to 53% for Subject 2167). During the second Lag-4 condition (Condition 3), the mean initial-link IRT decreased an average of 45% (range = 36% for Subject 8269 to 50% for Subject 2167).

Figures 5 and 6 show relative frequency distributions (in .5-s bins) of all initial- and terminal-link IRTs from the last five sessions of Conditions 1 and 2 for each subject. For all subjects, the mode of the distributions of initial-link IRTs shifted to the right during Condition 2, and/or decreased in height during this condition. The largest and smallest effects occurred for Subjects 2167 and 8269, respectively. The mode for Subject 2167 was in the first bin during both conditions, but whereas it comprised 78.1% of all IRTs from the last five sessions of Condition 1, it only comprised 21.8% of all IRTs from the corresponding sessions of Condition 2. The mode for Subject 8269 shifted from the first bin in

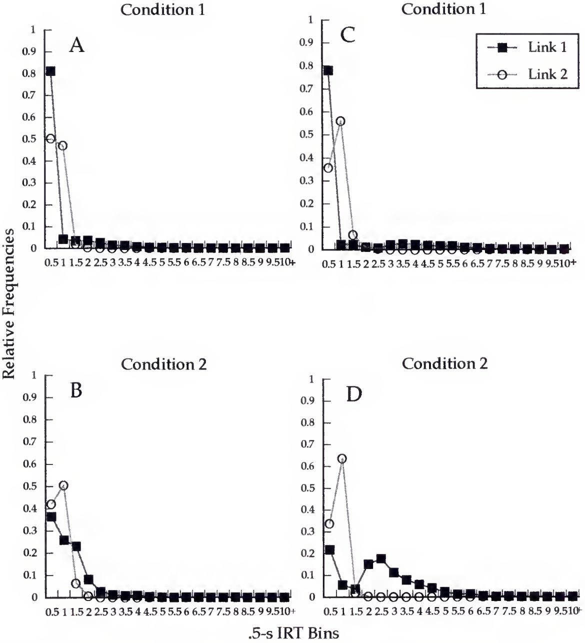

Figure 5. Relative frequency distributions of IRTs from two conditions of Experiment 1 for Subjects 68 and 2167. Parts A and B show, respectively, data from the last five sessions of Conditions 1 and 2 for Subject 68. Parts C and D show data from the last five sessions of Conditions 1 and 2 for Subject 2167. Lag-4 contingencies were in effect during Condition 1. Lag-0 contingencies were in effect during Condition 2.

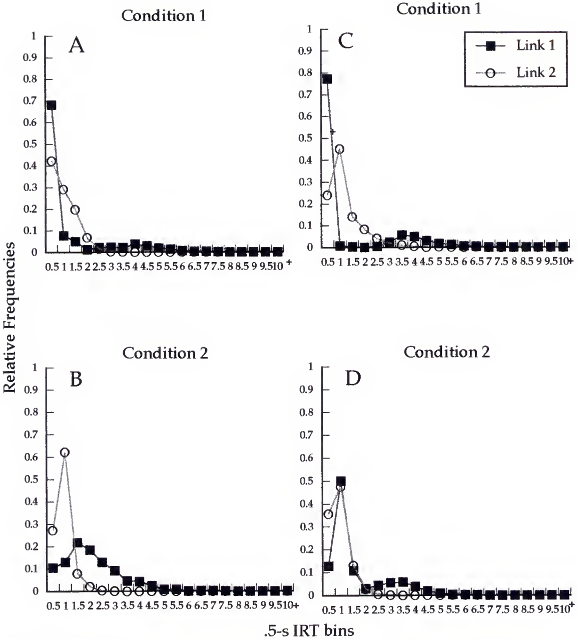

Figure 6. Relative frequency distributions of IRTs from two conditions of Experiment 1 for Subjects 790 and 8269. Parts A and B show, respectively, data from the last five sessions of Conditions 1 and 2 for Subject 790. Parts C and D show data from the last five sessions of Conditions 1 and 2 for Subject 8269. Lag-4 contingencies were in effect during Condition 1. Lag-0 contingencies were in effect during Condition 2.

Condition 1 to the second bin in Condition 2, but exhibited a more modest decrease in height. Specifically, the first and second bins comprised 77.3% and 50.1% of all IRTs from the last five sessions of Conditions 1 and 2, respectively. The distributions of terminal-link IRTs did not change reliably with the contingencies for any of the subjects.

Table 2 lists the medians (Q 2), and the 1st and 3rd quartiles (Q 1 and Q 3), of the latencies to the first initial- and terminal-link responses from the last 150 cycles of each condition for each subject. Comparisons of the interquartile ranges reveal that the distributions of initial-link latencies from adjacent conditions (i.e., Conditions 1 and 2, 2 and 3, and 3 and 4) overlapped considerably. Nevertheless, the median initial-link latencies were longer in the Lag-0 than in the preceding Lag-4 conditions in seven of eight possible comparisons (two comparisons per subject), whereas they were shorter during the return to baseline than during the preceding Lag-0 condition in all four possible comparisons.

The distributions of terminal-link latencies from adjacent conditions exhibited even more overlap, although for 3 subjects the medians varied systematically with the across-condition changes in the contingencies. The medians for Subjects 68 and 8269 were longer in the Lag-0 conditions than in the preceding Lag-4 conditions, whereas the median from the return to baseline (Condition 3) was shorter than that from the preceding Lag-0 condition for these subjects. The median latencies for Subject 2167 exhibited the opposite pattern of effects: That is, they were shorter during the Lag-0 than during the preceding Lag-4 conditions.

Table 2. Medians (Q2) and 1st and 3rd quartiles (Q1 and Q3) of the latencies to the first initial- and terminal-link responses from the last five sessions (150 cycles) of each condition for each subject. Lag-4 contingencies were in effect during Conditions 1 and 3. Lag-0 contingencies were in effect during Conditions 2 and 4. Conditions are listed by column; subjects are listed by row.

Subject			Condition			
			1	2	3	4
68	Link 1	Q1	2.71	3.07	1.42	2.22
		Q2	3.40	4.20	1.56	2.70
		Q3	4.29	5.27	1.69	3.07
	Link 2	Q1	0.12	0.23	0.22	0.30
		Q2	0.23	0.38	0.30	0.33
		Q3	0.40	0.64	0.36	0.38
790	Link 1	Q1	4.49	3.22	2.11	2.74
		Q2	5.76	4.53	2.49	4.01
		Q3	6.79	6.23	3.69	4.48
	Link 2	Q1	0.63	0.68	0.69	0.87
		Q2	0.68	0.90	0.92	0.96
		Q3	0.89	1.03	1.18	1.18
2167	Link 1	Q1	3.22	7.02	1.81	2.37
		Q2	5.26	8.74	2.10	3.09
		Q3	6.36	11.23	2.48	3.95
	Link 2	Q1	0.65	0.40	0.91	0.87
		Q2	0.98	0.62	1.25	1.18
		Q3	1.46	0.76	1.56	1.47
8269	Link 1	Q1	3.53	3.58	1.43	2.41
		Q2	4.41	4.81	1.63	3.45
		Q3	5.36	5.73	2.27	4.98
	Link 2	Q1	0.08	0.29	0.08	0.30
		Q2	0.29	0.36	0.31	0.31
		Q3	0.33	0.41	0.42	0.33

Discussion

The results of Experiment 1 demonstrate that IRT duration is sensitive to the probability of stimulus change, much as this response property is sensitive to the probability of food reinforcement. In particular, initial-link IRTs were longer when the probability of transitions to the terminal link varied directly with the duration of the most recent IRT, than when it varied directly with the duration of the fourth IRT in advance of the most recent one. Moreover, this effect occurred in the absence of systematic changes in the durations of the initial and terminal links, thus pointing to the contingency between responding and stimulus change (i.e., to conditioned reinforcement) as the most likely explanation.

The latencies to the first responses of the initial and terminal links (Table 2) also varied unsystematically with changes in the contingencies, as indicated by the overlapping distributions of latencies from adjacent conditions. However, the median latencies appeared to vary systematically with the across-condition changes in the contingencies in some cases. In particular, the medians from the initial link were somewhat longer in the Lag-0 than in the preceding Lag-4 conditions in seven of eight possible comparisons. Why this effect occurred is not clear, although one possibility is that initial-link latencies and initial-link IRTs are not functionally distinct properties of behavior. That is, even though latencies are measured from the presentation of the initial-link stimulus to the occurrence of the first response, and IRTs are measured as the time between one response and the next, both measures might be affected in similar ways by the contingencies of reinforcement.

Similarly, the median terminal-link latencies from both Lag-0 conditions were longer than those from the preceding Lag-4 conditions for two subjects and shorter for a third. Again, the reason for these effects is not obvious. One possibility, however, is that they might be functionally analogous to certain effects observed in studies involving two-component multiple schedules. In such studies, changes (decreases or increases) in response rates in one component frequently have been accompanied by similar (induction) or opposite (contrast) changes in the response rates of the other component (see Hemmes & Eckerman, 1972 and Reynolds, 1961 for examples of induction and contrast, respectively). One possibility, then, is that the factors responsible for induction and contrast in multiple schedules likewise might be responsible for the analogous effects upon the terminal-link latencies observed during the present study.

Whatever the validity of the foregoing speculations, the present results provide compelling evidence that IRT duration is sensitive to the probability of stimulus change (conditioned reinforcement), much as this response property is sensitive to the probability of food reinforcement. In addition, these findings raise the possibility that IRTs in chains comprised of more than two links (extended chains) also might be sensitive to reinforcement probability. This possibility was investigated in Experiment 2.

CHAPTER 3
EXPERIMENT 2

Although the results of Experiment 1 demonstrate that behavior in the initial link of a chain is sensitive to the probability of stimulus change, this sensitivity may be limited to two-link chained schedules. Perhaps the stimuli correlated with the early links of extended chains are too temporally distant from the unconditioned reinforcer to be endowed with conditioned-reinforcing properties, in which case, responding in the early links of extended chains would not be expected to be affected by the probability of transitions to later links. This possibility was alluded to by Catania, who asserted that "the stimulus changes in chained schedules have some reinforcing effects, but they're mostly restricted to the late components, close to the food reinforcers" (Catania, 1998, p. 186). Clearly, the stimulus correlated with the middle link of a three-link chain can function as a conditioned reinforcer, as the study by Royalty et al. (1987) showed. Nevertheless, there undoubtedly are limits beyond which stimuli correlated with the early links of extended chains are incapable of functioning in this capacity. In such cases, behavior would not be expected to be affected by the probability of stimulus change.

This issue was investigated in Experiment 2 by means of a four-link chained schedule, in which transitions between one link of the chain and the next were programmed according to linear-IRT contingencies similar to those used in Experiment 1. More specifically, transitions to the second, third, and fourth (terminal) links of the chain were contingent upon the duration of the IRTs in the first (initial), second, and third links, respectively. Subjects were exposed to both Lag-0 and Lag-4 contingencies, both of which were in effect during all but the baseline conditions, in which only the Lag-4 contingencies operated. That is, the experimental conditions differed from one another only in terms of the link in which the Lag-0 contingencies were in effect. In one condition, for example, transitions to the second link were contingent on Lag-0 IRTs in the first link, while transitions to the third and fourth links were contingent on Lag-4 IRTs in the second and third links, respectively.

As in Experiment 1, the Lag-4 contingencies were arranged, because they were expected to produce effects which might constitute a good point of reference for the effects of the Lag-0 contingencies. That is, the contingency between Lag-4 IRTs and component transitions was not expected to generate long IRTs, since IRTs of any duration might be more temporally contiguous to the onset of the stimulus correlated with the subsequent component than the IRT upon which the probability of component transitions was actually based. However, the contingency between Lag-0 IRTs and component transitions was expected to produce long IRTs, because of the high degree of temporal contiguity between the putative conditioned reinforcer and the IRT on which its presentation was contingent.

Method

The subjects and apparatus were those used in Experiment 1. A four-link chained schedule was used, in which Links 1 through 4 were correlated with blue, green, red, and white key lights, respectively. Both the transitions between links and the presentation of food in the terminal link were arranged by Linear-IRT schedules (see below).

Several characteristics of the procedures were the same as in Experiment 1, including the duration of food reinforcements (periods of access to the food hopper), the number of cycles per daily session, and the number of sessions per week. Also as in Experiment 1, the primary dependent measures collected from each link in each session were mean IRTs, absolute frequency distributions of all IRTs (in .5-s bins), the mean durations of each link, and all latencies to the first response in each link. Finally, for the same reasons which led to their exclusion in Experiment 1, the first four IRTs of each session and all latencies to the first response in each link were excluded from calculations of the probability of transitions between links, and from calculations of the probability of food presentations in the terminal link.

Eight experimental conditions were conducted, with the second series of four being a replication of the first series. Each series began with a baseline condition, in which the probability of all transitions between links (i.e, between Links 1 and 2, Links 2 and 3, and Links 3 and 4) were calculated by dividing the duration of Lag-4 IRTs by 15, the programmed duration (in seconds) of each link. In all other conditions, the probability of one of these transitions (e.g., that between Links 1 and 2) was calculated by dividing Lag-0 IRTs by 15, whereas the probability of the remaining transitions (e.g., that between Links 2 and 3 and that between Links 3 and 4) was based on Lag-4 IRTs. In all conditions, the probability of food reinforcement was calculated by dividing each Lag-4 IRT in the terminal link by 15.

Due to the complexity of the procedures, two letters and two numbers shall be used to designate a given condition, the letters L (for link) and S (for series), and the numbers 0 through 3. Specifically, Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 and L1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2, whereas the Lag-4 contingencies operated in every link during Conditions L0S1 and L0S2. The experimental conditions were partially counterbalanced across subjects (see Table 3 for each subject's order of exposure to the conditions).

Each condition remained in effect for a minimum of 15 sessions, and for as many additional sessions as were required for responding to meet the stability criteria. During the baseline conditions (Conditions L0S1 and L0S2), responding had to be stable in the link wherein the Lag-0 contingencies would be programmed during the subsequent condition. During the second and third conditions in each series, responding had to be stable in two links, that in which the Lag-0 contingencies were in effect, and that in which they would be programmed during the subsequent condition. Finally, in the last condition of each series, responding had to meet the stability criteria only in the link in which the Lag-0 contingencies were operating. In all other respects, the stability criteria were the same as in Experiment 1.

Results

Figures 7 through 10 show the mean IRTs from Links 1 through 4 (top graphs) and the mean durations of these links (bottom graphs) during the last five sessions of each condition for each subject. Taking up the latter measure first, the obtained mean durations of Links 1 through 4 varied unsystematically across conditions, and except in the case of Link 1, hovered around the

Table 3. Order of exposure to the experimental conditions for each subject. Lag-4 contingencies were in effect in every link during Conditions L0S1 and L0S2. Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 and L1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2. Numbers in parentheses indicate the number of sessions conducted in each condition. See text for additional details.

	Subject			
Condition	68	790	2167	8269
L0S1	1 (16)	1 (16)	1 (19)	1 (17)
L1S1	4 (43)	2 (36)	4 (21)	2 (23)
L2S1	3 (15)	3 (15)	3 (52)	3 (15)
L3S1	2 (19)	4 (20)	2 (17)	4 (49)
L0S2	5 (19)	5 (20)	5 (17)	5 (15)
L1S2	8 (20)	6 (37)	8 (25)	6 (52)
L2S2	7 (60)	7 (36)	7 (15)	7 (38)

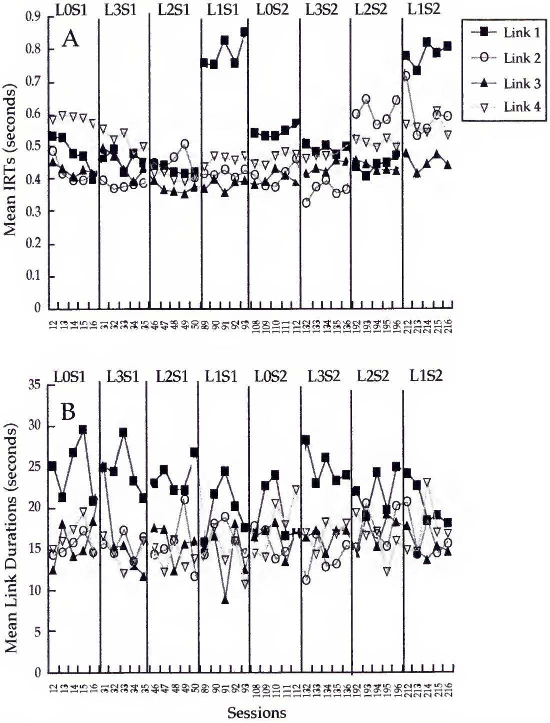

Figure 7. Summary of the results from Experiment 2 for Subject 68. Part A of the figure shows the mean IRTs in Links 1 through 4. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect during conditions L0S1 and L0S2. Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 and L1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2.

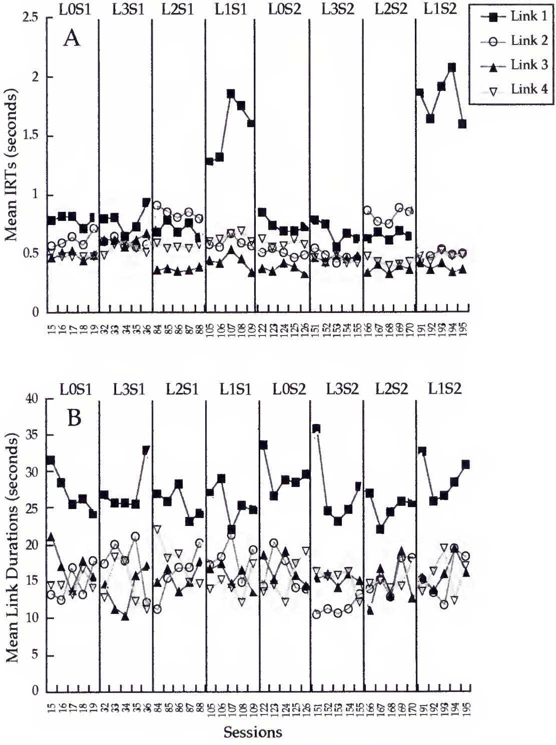

Figure 8. Summary of the results from Experiment 2 for 2167. Part A of the figure shows the mean IRTs in Links 1 through 4. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect in every link during conditions L0S1 and L0S2. Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 and L1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2.

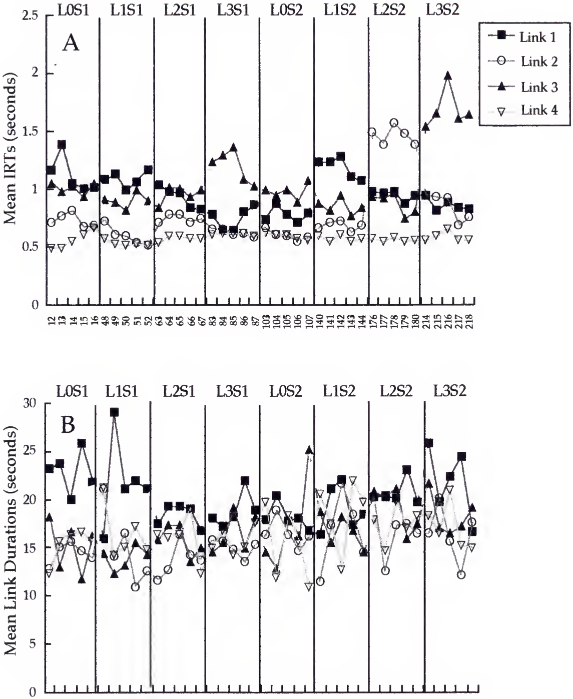

Figure 9. Summary of the results from Experiment 2 for Subject 790. Part A of the figure shows the mean IRTs in Links 1 through 4. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect during Conditions L0S1 and L0S2. Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 andL1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2.

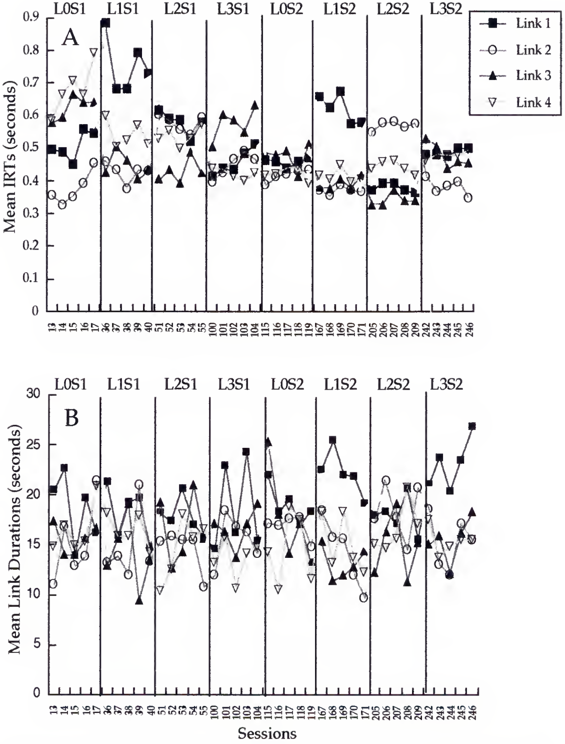

Figure 10. Summary of the results from Experiment 2 for Subject 8269. Part A of the figure shows the mean IRTs in Links 1 through 4. Part B shows the mean durations of these links. Data are from the final five sessions of each condition. Lag-4 contingencies were in effect during conditions L0S1 and L0S2. Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 and L1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2.

programmed mean. The mean durations of Links 2 through 4 (calculated from the last 150 cycles of each condition) ranged from 13.2 s (Subject 8269, Condition L1S2, Link 3) to 19.1 s (Subject 790, Condition L2S2, Link 3). In contrast, the Link-1 means (calculated in the same manner as for the other links) ranged from 17.7 s (Subject 8269, Condition L2S1) to 29.4 s (Subject 2167, Condition L0S2).

One reason for the discrepancy between the programmed and obtained durations for Link 1 might be that the Link-1 latencies were much longer than the latencies in the other three links (see Tables 4 and 5). To investigate this possibility, the Link-1 latencies from the last 150 cycles of each condition were averaged, and these averages were subtracted from the mean Link-1 durations. Adjusted in this manner, the mean durations for Link 1 ranged from 13.8 s (Subject 2167, Condition L2S2) to 18.1 s (Subject 8269, Condition L3S2), suggesting that the difference between the obtained and programmed durations for Link 1 can be attributed to the length of the Link-1 latencies.

As with the durations of each link, the mean Link-4 IRTs varied unsystematically across conditions for all subjects. This outcome was expected, given that the contingencies of reinforcement in this link were held constant across conditions. That is, the probability of food reinforcement varied directly with the duration of the Lag-4 IRT throughout the experiment.

With two exceptions (Subject 68, Condition L2S2; Subject 790, Condition L1S1), the mean IRTs from Links 1 through 3 varied as a function of whether the Lag-0 or the Lag-4 contingencies were in effect. Note that the Lag-0 contingencies tended to produce larger increases in the duration of the Link-1 IRTs than in the duration of the Link-2 IRTs, which in turn tended to be longer

Table 4. Medians (Q2) and 1st and 3rd quartiles (Q1 and Q3) of the latencies to the first responses of each link from the last five sessions (150 cycles) of each condition for Subjects 68 and 2167. Lag-4 contingencies were in effect in all links during Conditions L0S1 and L0S2. Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 and L1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2. Conditions are listed by column in the order in which they were conducted. Subjects are listed by row.

Subject			Condition							
			L0S1	L3S1	L2S1	L1S1	L0S2	L3S2	L2S2	L1S2
68	Link 1	Q1	5.61	6.52	5.54	3.05	3.86	5.30	4.58	3.33
		Q2	6.79	7.38	6.88	3.73	4.85	6.75	6.74	3.73
		Q3	7.94	9.19	7.77	5.07	5.88	8.22	8.57	5.21
	Link 2	Q1	0.10	0.09	0.09	0.22	0.13	0.10	0.09	0.21
		Q2	0.11	0.11	0.11	0.27	0.25	0.13	0.11	0.30
		Q3	0.26	0.15	0.23	0.44	0.37	0.29	0.17	0.55
	Link 3	Q1	0.10	0.10	0.15	0.11	0.11	0.11	0.21	0.14
		Q2	0.14	0.13	0.25	0.21	0.22	0.17	0.37	0.37
		Q3	0.33	0.37	0.36	0.37	0.38	0.38	0.46	0.56
	Link 4	Q1	0.23	0.29	0.27	0.23	0.21	0.26	0.25	0.23
		Q2	0.33	0.37	0.31	0.33	0.34	0.35	0.33	0..31
		Q3	0.40	0.44	0.34	0.39	0.38	0.43	0.41	0.38
2167	Link 1	Q1	9.60	9.04	7.06	7.35	10.82	8.23	9.34	11.67
		Q2	10.82	10.55	8.56	8.04	12.71	9.57	10.79	13.22
		Q3	12.49	11.97	9167	9.38	14.56	12.17	12.46	14.73
	Link 2	Q1	0.17	0.24	0.07	0.37	0.13	0.08	0.08	
		Q2	0.32	0.31	0.29	0.43	0.32	0.30	0.28	0.36
		Q3	0.36	0.36	0.38	1.00	0.93	0.39	0.37	
	Link 3	Q1	0.09	0.08	0.29	0.12	0.08	0.07	0.28	0.08
		Q2	0.34	0.17	0.36	0.34	0.31	0.11	0.38	0.28
		Q3	1.23	0.94	0.93	1.04	1.34	0.32	1.09	0.34
	Link 4	Q1	0.25	0.06	0.07	0.06	0.06	0.07	0.07	0.08
		Q2	0.62	0.61	0.37	0.37	0.34	0.33	0.34	0.34
		Q3	0.86	0.67	0.61	0.66	0.62	0.55	0.39	0.68

Table 5. Medians (Q2) and 1st and 3rd quartiles (Q1 and Q3) of the latencies to the first responses of each link from the last five sessions (150 cycles) of each condition for Subjects 790 and 8269. Lag-4 contingencies were in effect in all links during Conditions L0S1 and L0S2. Lag-0 contingencies were in effect in Link 1 during Conditions L1S1 and L1S2, in Link 2 during Conditions L2S1 and L2S2, and in Link 3 during Conditions L3S1 and L3S2. Conditions are listed by column in the order in which they were conducted. Subjects are listed by row.

Subject			Condition							
			L0S1	L1S1	L2S1	L3S1	L0S2	L1S2	L2S2	L3S2
790	Link 1	Q1	2.85	4.53	2.67	2.50	2.57	2.29	3.64	2.79
		Q2	6.64	5.20	3.10	2.90	3.20	2.84	4.31	3.44
		Q3	8.23	6.38	3.68	5.02	4.99	3.71	6.47	4.38
	Link 2	Q1	0.39	0.54	0.52	0.53	0.54	0.54	0.64	0.58
		Q2	0.58	0.59	0.56	0.57	0.60	0.59	1.13	0.61
		Q3	0.70	0.69	0.61	0.60	0.90	0.92	1.56	0.66
	Link 3	Q1	0.51	0.53	0.60`	1.15	1.00	1.48	2.93	2.21
		Q2	0.55	0.58	0.90	1.45	1.49	2.37	3.96	4.63
		Q3	0.61	0.92	1.50	1.76	2.52	3.29	4.62	6.14
	Link 4	Q1	0.94	0.63	0.69	0.69	0.84	0.95	1.20	1.49
		Q2	1.08	0.91	1.03	0.98	0.95	1.19	1.76	2.31
		Q3	1.47	1.03	1.21	1.36	1.19	1.70	2.84	2.80
8269	Link 1	Q1	3.01	2.72	2.61	2.78	3.00	4.04	3.40	4.19
		Q2	3.69	3.15	2.98	3.25	3.47	4.62	4.12	4.91
		Q3	4.39	3.88	4.08	3.81	4.13	5.13	4.65	5.76
	Link 2	Q1	0.07	0.06	0.07	0.08	0.10	0.16	0.06	0.07
		Q2	0.30	0.29	0.30	0.30	0.30	0.26	0.25	0.25
		Q3	0.32	0.32	0.32	09.34	0.34	0.31	0.30	0.31
	Link 3	Q1	0.07	0.08	0.07	0.06	0.06	0.06	0.05	0.06
		Q2	0.26	0.28	0.31	0.26	0.22	0.21	0.07	0.19
		Q3	0.33	0.33	0.35	0.36	0.35	0.25	0.32	0.31
	Link 4	Q1	0.09	0.26	0.28	0.07	0.08	0..08	0.08	0.09
		Q2	0.33	0.30	0.32	0.27	0.29	0.23	0.26	0.27
		Q3	0.59	0.38	0.56	0.31	0.39	0.31	0.31	0.35

than the Link-3 IRTs. Averaged across subjects, the mean Link-1 IRT increased by 85% with the Lag-0 contingencies (range = 35% for Subject 8269, Condition L1S2 to 180% for Subject 2167, Condition L1S2). The mean Link-2 IRT increased an average of 54% during the Lag-0 conditions (range = 19% for Subject 68, Condition L2S1 to 115% for Subject 790, Condition L2S2), and the mean Link-3 IRT increased an average of 32% (range = 3% for Subject 68, Condition L3S1 to 93% for Subject 790, Condition L3S2). With the reinstatement of the Lag-4 contingencies, the mean Link-1 IRT decreased an average of 30% (range = 15% for Subject 790, Condition L2S1 to 53% for Subject 2167, Condition L0S2). The average decrease in the Mean Link-2 IRT was 24% (range = 2% for Subject 68, Condition L1S2 to 42% for Subject 790, Condition L3S2), and the average decrease in the Mean Link-3 IRT was 23% (range = 17% for Subject 68, Condition L2S1; Subject 8269, Condition L0S2 to 41% for Subject 2167, Condition L2S1).

Another characteristic of these results that may be worth noting is that the magnitude of the effects of the Lag-0 contingencies on the Link-1 and the Link-3 IRTs depended upon the order in which subjects were exposed to the experimental conditions. Specifically, the Lag-0 contingencies produced larger increases in the duration of the Link-1 IRTs for Subjects 68 and 2167 than for Subjects 790 and 8269, whereas they produced larger increases in the Link-3 IRTs for the second pair of subjects than for the first pair (Table 3). As the variables responsible for this effect are not readily apparent, nothing more will be said about this issue in what follows.

Figures 11 through 14 show relative frequency distributions (in .5-s bins) of all IRTs from each link of the last five sessions in Conditions L0S1, L1S1, L2S1,

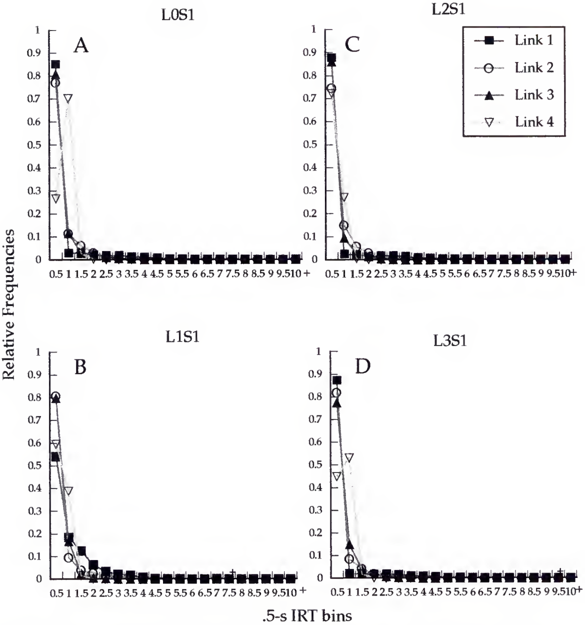

Figure 11. Relative frequency distributions of IRTs for Subject 68. Parts A through D of the figure show data from the last five sessions of Conditions L0S1, L1S1, L2S1, and L3S1, respectively. Lag-4 contingencies were in effect in all links during Condition L0S1. Lag-0 contingencies were in effect in Link 1 during Condition L1S1, in Link 2 during Condition L2S1, and in Link 3 during Condition L3S1.

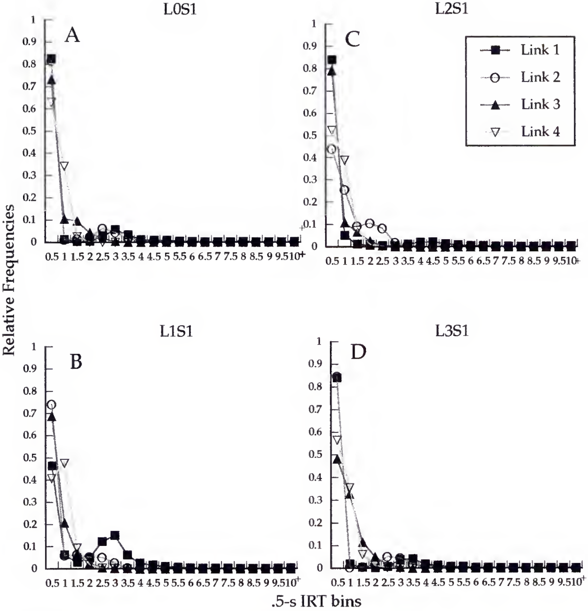

Figure 12. Relative frequency distributions of IRTs for Subject 2167. Parts A through D of the figure show data from the last five sessions of Conditions L0S1, L1S1, L2S1, and L3S1, respectively. Lag-4 contingencies were in effect in all links during Condition L0S1. Lag-0 contingencies were in effect in Link 1 during Condition L1S1, in Link 2 during Condition L2S1, and in Link 3 during Condition L3S1.

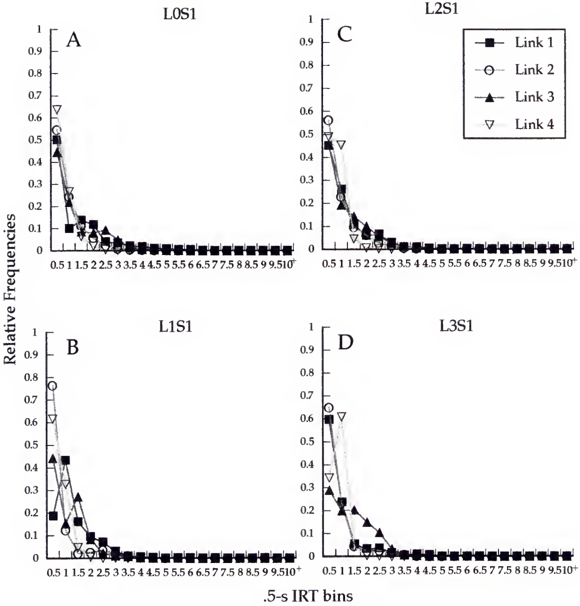

Figure 13. Relative frequency distributions of IRTs for Subject 790. Parts A through D of the figure show data from the last five sessions of Conditions L0S1, L1S1, L2S1, and L3S1, respectively. Lag-4 contingencies were in effect in all links during Condition L0S1. Lag-0 contingencies were in effect in Link 1 during Condition L1S1, in Link 2 during Condition L2S1, and in Link 3 during Condition L3S1.

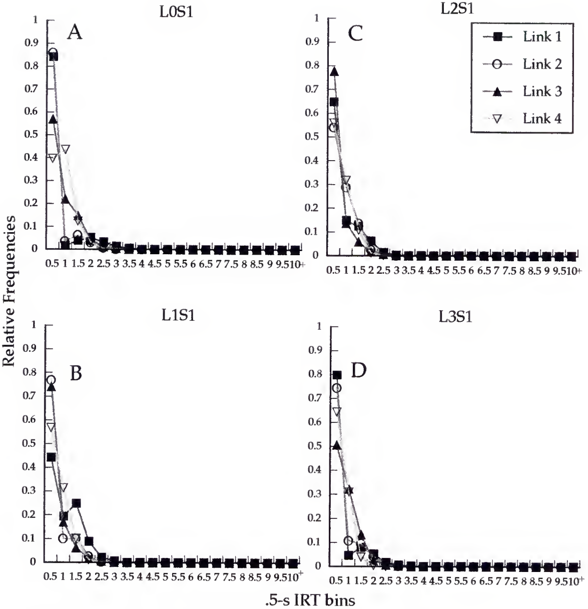

Figure 14. Relative frequency distributions of IRTs for Subject 8269. Parts A through D of the figure show data from the last five sessions of Conditions L0S1, L1S1, L2S1, and L3S1, respectively. Lag-4 contingencies were in effect in all links during Condition L0S1. Lag-0 contingencies were in effect in Link 1 during Condition L1S1, in Link 2 during Condition L2S1, and in Link 3 during Condtion L3S1.

and L3S1). The distributions from Link 4 varied unsystematically across conditions, whereas those from the other three links changed primarily with respect to the frequency of IRTs in the first bin.

For example, the height of the first (modal) IRT bin of the Link-1 distributions decreased for all subjects but 790. Of the remaining distributions, the largest and smallest effects occurred for Subjects 8269 and 68, respectively. For Subject 8269, the mode of the distributions comprised 44% of all Link-1 IRTs from the last five sessions of Condition L1S1, and 84% of all Link-1 IRTs from the corresponding sessions of Condition L0S1 (the previous condition). For Subject 68, the mode comprised 54% of all Link-1 IRTs from the last five sessions of Condition L1S1, and 88% of all Link-1 IRTs from the corresponding sessions of the preceding condition (Condition L2S1).

With one possible exception (Subject 68), the modal IRT bin of the Link-2 distributions also decreased in height as a function of the Lag-0 contingencies. The largest effect occurred for Subject 2167, for which the mode of the distributions comprised 44% of all Link-2 IRTs from the last five sessions of Condition L2S1, and 85% of all Link-2 IRTs from the corresponding sessions of Condition L3S1 (the previous condition). The smallest effect occurred for Subject 790, for which the mode comprised 56% of all Link-2 IRTs from the last five sessions of Condition L2S1, and 76% of all Link-2 IRTs from the corresponding sessions of the preceding condition (Condition L1S1).

In Link 3, the Lag-0 contingencies produced a modest decrease in the height of the modal IRT bin in three cases, and no decrease at all in the fourth (Subject 68). The largest and smallest effects occurred for Subjects 8269 and 790, respectively. For Subject 8269, the mode of the distributions comprised 51% of all Link-3 IRTs from the last five sessions of Condition L3S1, and 78% of all Link-3 IRTs from the corresponding sessions of Condition L2S1 (the previous condition). For Subject 790, the mode comprised 29% of all Link-3 IRTs from the last five sessions of Condition L3S1, and 46% of all Link-3 IRTs from the corresponding sessions of the preceding condition (Condition L2S1).

Tables 4 and 5 list the medians, (Q 2) and the 1st and 3rd quartiles, (Q 1 and Q 3) of the latencies to the first responses of each link from the last 150 cycles of each condition for each subject. As in Experiment 1, the interquartile ranges from adjacent conditions overlap considerably. Unlike that experiment, however, the median latencies only varied systematically across conditions in a few cases, and in several of these, the effects were negligible. In particular, the median Link-1 latency decreased for Subject 68 during Conditions L1S1 and L1S2 (the first and second Lag-0 conditions, respectively) and increased during Condition L0S2, which followed the first Lag-0 condition for this subject. Likewise, the median Link-2 latency for Subject 2167 decreased when the Lag-0 contingencies were in effect (Conditions L2S1 and L2S2), and increased when the Lag-4 contingencies were reinstated (Conditions L1S1 and L1S2). As just alluded to, however, the decreases in the median Link-2 latency was quite small for this subject (less than .1 s). The median Link-3 latency decrease for two subjects (Subjects 2167 and 68) during both Lag-0 conditions (Conditions L3S1 and L3S2), and increased when the Lag-4 contingencies were reinstated (Conditions L2S1 and L2S2). Again, the decreases in the median Link-3 latency for Subject 68 was not significant (also less than .1 s). Finally, no systematic across-condition changes could be discerned in the median latencies from Link 4.

Discussion

The results of Experiment 2 demonstrate that IRTs in the early links of a four-link chained schedule are affected by the probability of stimulus change, much as IRTs in the initial link of a two-link chained schedule are affected. In all but two cases, IRTs in Links 1 through 3 increased in duration when the Lag-0 contingencies were in effect, and then decreased in duration when the Lag-4 contingencies were reinstated. Such findings cannot be attributed to the delays to the unconditioned reinforcer signaled by the stimuli correlated with the different links of the chain, nor can they be ascribed to the contingency between rate of responding in the early links and the delay to the unconditioned reinforcer, because the linear-IRT schedules used to arrange transitions between links controlled for the effects of these variables. Consequently, these findings can only be accounted for in terms of the contingency between responding and stimulus change.

What such an account fails to explain, however, is why the effects of the Lag-0 contingencies varied inversely with distance from the next food reinforcement (i.e., why the largest and smallest increases in IRT duration occurred in Links 1 and 3, respectively). One possibility worth considering is that this finding might be due to the interaction between response-stimulus (R-S) and stimulus-stimulus (S-S) contingencies. The ability of S-S contingencies to generate and maintain key pecking has been amply demonstrated (Brown & Jenkins, 1968), as has the interaction between R-S and S-S contingencies in chained schedules (Dougherty & Lewis, 1991). Dougherty and Lewis arranged a discrete-trials procedure, in which a key peck in the initial link of a two-link chained schedule canceled the presentation of the terminal link, and thus of food reinforcement. Despite the negative correlation between pecking in the initial link, on the one hand, and the presentation of the terminal-link stimulus and food, on the other, a high number of key pecks occurred in the initial link, suggesting that the pairings of the initial- and terminal-link stimuli (S-S contingency) competed for control against both of the R-S contingencies (i.e., that between initial-link responding and the presentation of the terminal-link stimulus, and that between initial-link responding and food reinforcement).

Where the results of Experiment 2 are concerned, such findings suggest that the effects of the Lag-0 contingencies may have been attenuated by those of the S-S contingencies in the later links of the chain. In other words, high rates of elicited key pecks might have competed with the occurrence of long pauses between such pecks, thereby placing limits on the ability of the Lag-0 contingencies to generate long IRTs. To be sure, this account is highly speculative, based as it is on two untested assumptions: that the stimuli correlated with the earlier links of extended chains acquire their eliciting function by means of higher-order Pavlovian conditioning, and that the ability of these stimuli to elicit key pecking diminishes with their distance from the next food presentation. If correct, however, it would explain why the magnitude of the effects of the Lag-0 contingencies varied inversely with temporal distance from the next food reinforcement. That is, the Lag-0 contingencies would have produced the largest increases in IRT duration during Link 1, because few if any elicited key pecks would have competed with long pauses between pecks in that link. Conversely, the Lag-0 contingencies would have generated the smallest increases in IRT duration in Link 3, because the high number of elicited key pecks in this link would have been incompatible with long periods of waiting to peck.

CHAPTER 4
GENERAL DISCUSSION

The purpose of the two experiments reported herein was to examine whether behavior in chained schedules is sensitive to response-contingent variations in the probability of stimulus change. Experiment 1 demonstrated that IRTs in the initial link of a two-link chained schedule will increase in duration when the probability of transitions to the terminal link varies as a direct function of the duration of the most recent IRT, but that initial-link IRTs will not increase in duration when the probability of such transitions varies directly with the length of the fourth IRT in advance of the most recent one. Experiment 2 showed that IRTs in the early links of a four-link chain also will vary in length, depending on whether the probability of transitions from one link to the next is based upon the duration of the most recent IRT or not. Because the procedures used in both experiments kept the duration of each link from varying systematically across conditions, these findings cannot be accounted for in terms of the delays to the unconditioned reinforcer signaled by the stimuli correlated with the different links in the chains, or in terms of the contingency between rate of responding in each link and the presentation of the unconditioned reinforcer. Consequently, these results must be attributed to the contingency between responding and stimulus change.

At a more theoretical level, the present findings suggest that accounts of chained-schedule performance that disregard the effects of conditioned reinforcement may be in error. As alluded to in the introduction, one such account is presented by Staddon, who asserted that "The concept of conditioned reinforcement (that is, the response contingency between pecking and stimulus change) adds nothing to our understanding of chained schedules," and that "Behavior on chained schedules is determined by temporal proximity to food in the same way as behavior on multiple schedules" (Staddon, 1983; p. 466). Contrary to such assertions, the response-stimulus contingencies in the present studies had clear effects upon responding, which cannot be attributed to the delay-signaling function of the stimuli correlated with the different links of the chains.

Additional research is needed, however, to determine the generality of these effects. For example, it is not clear whether the sensitivity of behavior to the probability of stimulus change depends upon the duration of the interfood interval (IFI), because only one IFI duration (60 s) was arranged in the present studies. Similarly, future research will be needed to determine the upper limit in the number of links that can comprise a chain, before the probability of component transitions no longer affects responding in the initial link.

Other research questions likewise arise from the present findings. First, it is not clear whether responding in the early links of a chained schedule is maintained by the offset of the stimulus correlated with that link (conditioned negative reinforcement), or whether it is maintained by the onset of the stimulus correlated with the subsequent link (conditioned positive reinforcement). In Experiment 2, for example, the stimulus correlated with the first link of the chain might have become a powerful conditioned negative reinforcer, either because of its temporal distance from the next presentation of the unconditioned reinforcer, or because of being paired with the removal of the unconditioned reinforcer, which also may be assumed to be an aversive event. Either way, the offset of the Link-1 stimulus might have become a more powerful source of reinforcement than the onset of either the Link-2 or the Link-3 stimuli. Similarly, the offset of the Link-2 stimulus might have become a more powerful reinforcing event than the onset of the Link-3 stimulus, either because of its temporal distance from the next presentation of the unconditioned reinforcer, or because of being paired with the offset of the Link-1 stimulus. Such speculations have little empirical support, although one study did find that responding can be maintained in the terminal link of a two-link chain if it postpones the return to the initial link (Thomas, 1966), suggesting that the offset of stimuli in the early links of extended chains likewise might function as conditioned negative reinforcement.

Second, the present findings raise certain questions pertaining to the topic of response shaping (i.e., the process whereby new behavior is generated out of old through the differential reinforcement of successive approximations). In particular, these findings show that long IRTs can be shaped by the stimulus changes correlated with the transitions between links. In so doing, they raise a number of questions: for example, whether other properties of behavior also can be shaped by means of conditioned reinforcement, whether shaping with conditioned reinforcers is affected by the same variables that have been found to govern response shaping by means of unconditioned reinforcement (Galbicka & Platt, 1986; Machado, 1989, Experiment 2), whether shaping proceeds more rapidly as a function of conditioned or of unconditioned reinforcement (or vice versa), and so on.

In addition to being of interest in their own right, such questions have the potential to increase our understanding of how human behavior is acquired. One possibility, for example, is that conditioned reinforcement shapes vocal behavior during the acquisition of language by infants (Williams, 1994). The basic idea is that the auditory stimuli produced by an infant's vocal behavior reinforce such behavior, to the extent that they resemble the auditory stimuli produced by the vocalizations of the adults who care for that infant. In turn, the sounds produced by the adult caregivers' vocal behavior are supposed to acquire conditioned-reinforcing properties for the infant's vocal responding, as a result of being paired with unconditional stimuli such as those that arise from eating, the removal of cold and wet clothing, and so on. To illustrate, the vocal behavior of infants raised in an English-speaking household increasingly comes to resemble standard English, perhaps because the speech sounds produced by the infants' vocalizations increasingly resemble adult speech sounds, which in turn might have acquired their conditioned-reinforcing properties by being paired with food, the removal of wetness, and so forth. At present, the roles of conditioned reinforcement and response shaping in the acquisition of human behavior are not understood, because the necessary research has not been conducted. In this regard, the present finding, that a specific property of behavior can be differentiated by means of conditioned reinforcement, can be seen as constituting a point of departure for such research.

Of greater significance for the purpose of the present studies, however, is the finding that behavior in chained schedules is affected by the probability of stimulus change, just as responding in simple schedules is affected by the probability of food reinforcement. This finding firmly establishes the concept of conditioned reinforcement as necessary for a complete explanation of the behavior generated and maintained by chained schedules, and in so doing, challenges the validity of accounts of chained-schedule performance that ignore this concept.

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BIOGRAPHICAL SKETCH

Rafael Bejarano is a native of Mexico who moved to the United States at the age of 9. After graduating from high school in Tucson, Arizona, he was employed as a professional musician for several years. In the spring of 1995, Rafael obtained his Bachelor of Arts in Psychology from Prescott College, a liberal arts college in Prescott, Arizona, and in the fall of the same year, he began his graduate studies in psychology at the University of Florida, where he obtained his Master's degree. Rafael currently resides in Parsons, Kansas with his wife and daughter.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Timothy D. Hackenberg, Chair
Associate Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Timothy R. Vollmer
Assistant Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

W. Keith Berg
Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

MM Branch

Marc N. Branch
Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Cecil Mercer

Cecil Mercer
Distinguished Professor of Special Education

This dissertation was submitted to the Graduate Faculty of the Department of Psychology in the College of Liberal Arts and Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Dean, Graduate School